ADVANCED STRUCTURAL ANALYSIS OF SILICON SOLAR CELLS

Nikola Papež
Doctoral Degree Program (3), FEEC BUT
E-mail: Nikola.Papez@vutbr.cz

Supervised by: Dinara Sobola
E-mail: sobola@vutbr.cz

Abstract: The study investigates the structural imperfections of photovoltaic cells based on polycrystalline silicon. Experimental characterization focuses in particular on the degradation and defects analysis. Two modern techniques were used – scanning electron microscopy (SEM) with electron beam induced current (EBIC) and 3D digital optical microscopy. The properties and range of cell defects that can significantly affect its function were characterized with this inspection and failure analysis.

Keywords: SEM, EBIC, optical microscopy, solar cells, defects

1 INTRODUCTION

Electron microscopy with EBIC is mostly used for semiconductor analysis and characterization, such as surface and subsurface defect detection, contamination analysis and pn junction visualization in sample cross-section. It can also be used to measure IV characteristics and depletion region thickness measurements [6].

A large number of electron-hole pairs are generated during using an electron beam when observing a sample with an electron microscope. In the case of a pn or Schottky junction, the pair of electron-hole may be separated by an internal electric field which will drift electrons and holes to the n and p side. The p and n sides of the sample are then connected via the current amplifier. Separated electrons and holes flow through the circuit and create an electron beam induced current (EBIC). In the next step the current amplifier output is used as a SEM imaging signal [5].

Compared to electron microscopy, digital optical microscopy in three-dimensional mode offers a complete overview of the sample structure. Its advantage lies in the far better handling of the sample and its non-destructive analysis of non-conductive particles and features on the surface with very good dynamic contrast range (DHR+). These possibilities are harder to achieve with SEM [7, 8].

Using of EBIC method as well as the observation of the structure by an 3D optical microscope appears as very prospective and effective method for the analysis of structural imperfections of the solar cells.

2 MATERIALS AND METHODS

The subject of the investigation was polycrystalline silicon photovoltaic cells. Thanks to their material properties and purchase price it is the most used type of solar cell at all. For this reason it is desirable to focus to the analysis of surface and subsurface defects [4, 2].

Prior to measurement, the sample was cleaned in an ultrasonic cleaner. For LYRA3 electron microscope measurements samples were connected using nanomanipulators with two very precise needles mounted on motorized arms. This connection method was used as a solar cell has no direct cable termination. The position of the photovoltaic cell and thus also the pn junction, was perpendicular to the electron beam, referred to as the plain view (PV-EBIC). The generated current is measured by a pico-ampermeter inside the detector, then the signal is converted to digital by a converter (ADC), processed by a digital processor (DSP) and connected to a computer as described in the Figure 1. The SEM accelerating voltage was set to 10 kV with applied forward 0.8 V bias voltage. With this bias voltage various types of electrical junctions were clearly visible. It is also influenced by the sensitivity of the detector.

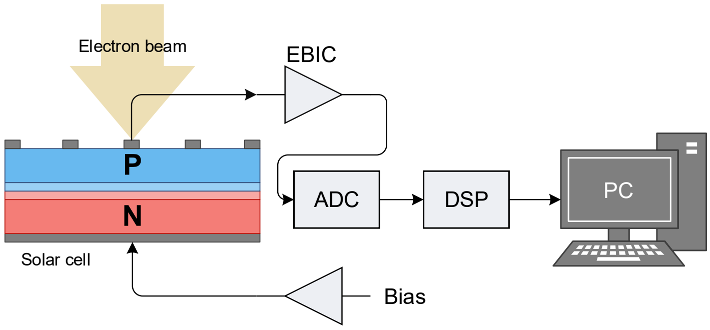


Figure 1: Wiring diagram for EBIC method.

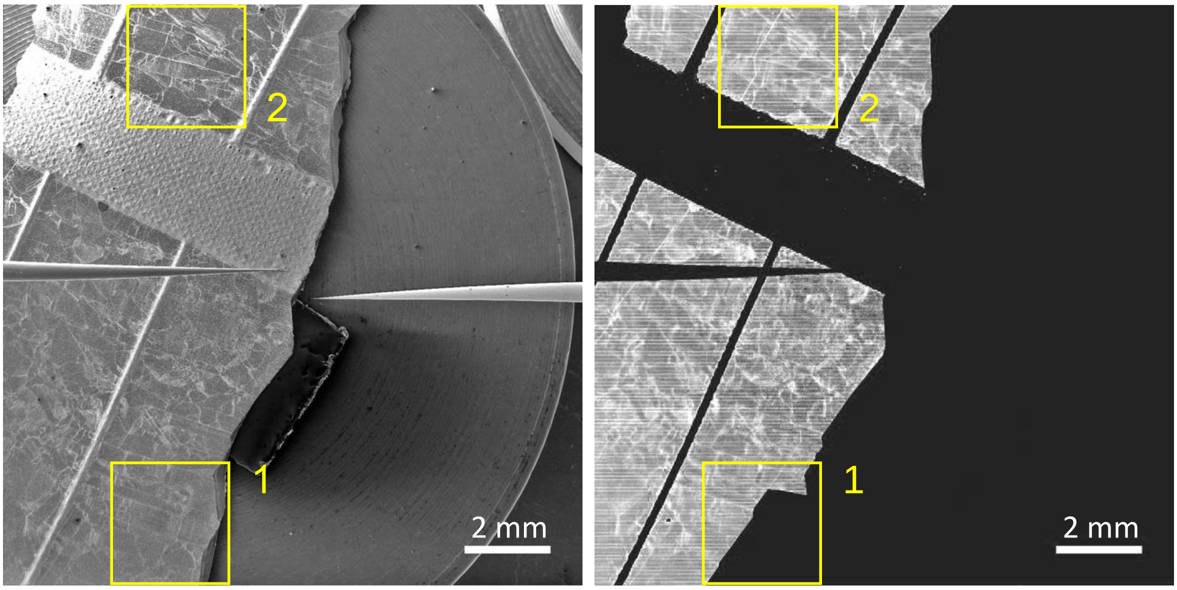
By measuring the Keyence VHX-6000 digital optical microscope under standard ambient temperature and pressure (25 °C, 101 kPa), it has been evaluated the exact dimensions of the contacts. It was also observed other features and surface degradation including oxidation. Some of these imperfections, such as organic impurities are not easily localized by electron microscopy due to degradation of the sample with an electron beam. This contamination can occur during cleaning, handling or cutting of samples. The reason for choosing the device was rapid and extensive analysis under very high DHR, which would not be in other cases easily feasible. This has been achieved thanks to optimized lighting from three sides and Depth from Defocus Depth (DFD) function with up to 5000× magnification.

3 RESULTS

Below, from the EBIC measurement results in the set in Figure 2 a solar cell placed on the holder can be seen using a conductive carbon tape. The connection with the nanomanipulators was through the top contact of the cell and through its holder. If the pn junction is not ideal and contains some resistive impurities or leads, the induced current may decrease. Figure 2b shows the contrast between the silver contacts and the silicon surface, and the induced current between the two interfaces. It can also be seen that the cell surface is not completely homogeneous and indicates the occurrence of various failures and other impact of degradation and impurities [1].

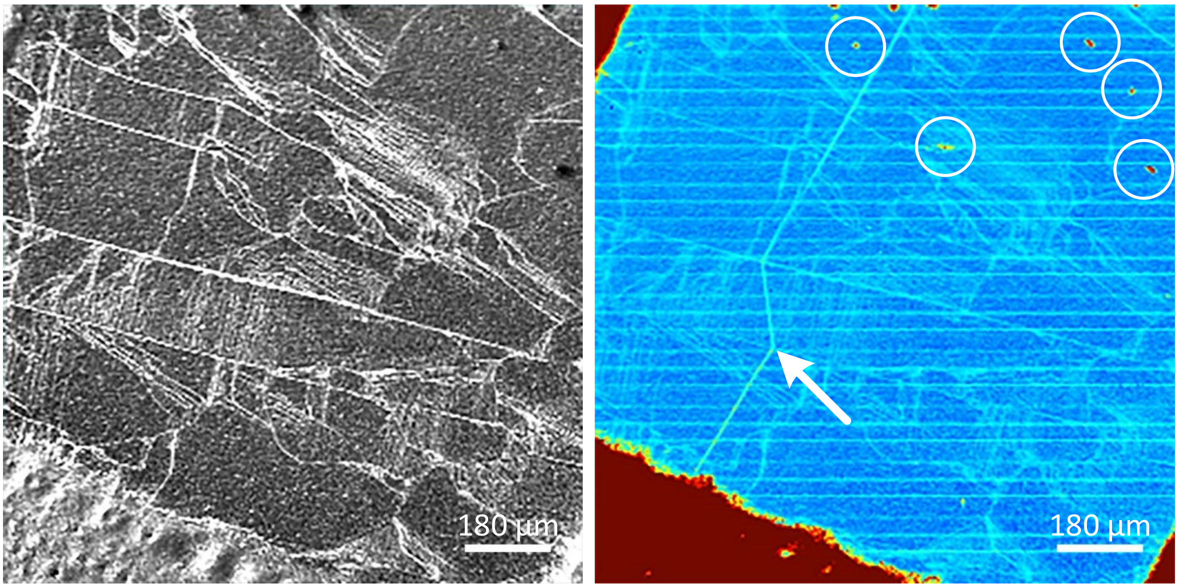
In the picture can be also noticed a two points of interest, which are marked by a yellow frame. If we focus on frame number 1 and compare its contents between Figure 2a and 2b, we can observe the completely inactive part of the solar cell surface, which is presented by EBIC by a strong cut. However, this part of the surface is not visible in Figure 2a from SEM at all. The second yellow frame with the number 2 then represents the Figure 3 for better illustration. In addition to the small impurities on which the white circles show a subsurface crack can be observed across the cell surface, which is also not evident from the first Figure 3a. These cracks occurred in multiple parts of the solar cell and their uniformity and rare appearance confirm that cannot be confused with grain boundaries.

The next part of the measurement was focused on the silver contacts of the cell using an optical microscope (see Figure 4). The exact surface structure and the inhomogeneously applied contact on the cell can be seen from the three-dimensional view in Figure 4a. The contact height profile was measured, as indicated by the 2D measurement where are marked crosses in Figure 4b and Figure 5.



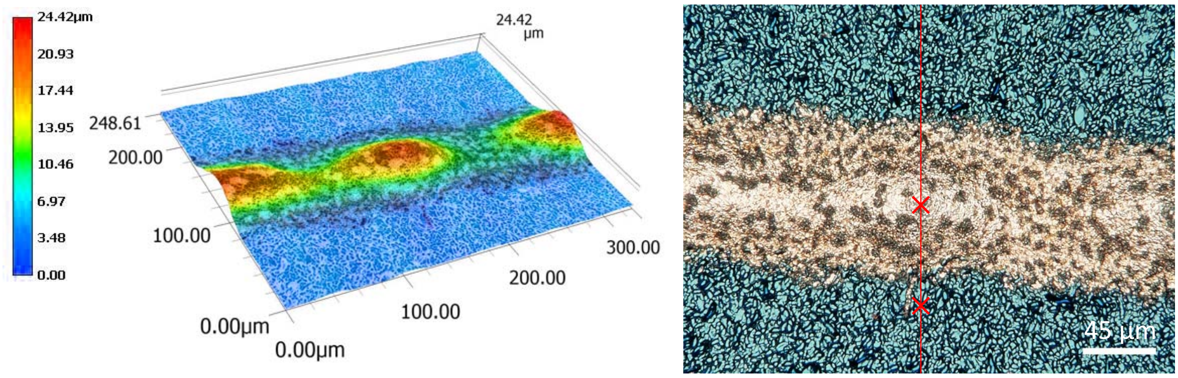
a) b)

Figure 2: Solar cell scanned by a) SEM microscope using b) a grayscale EBIC method.



a) b)

Figure 3: Detail of the solar cell surface and b) one of the subsurface and other defects measured by colored EBIC which cannot be clearly seen in Figure a) from electron microscope.



a) b)

Figure 4: Examination of quality and uniformity of silver contacts in a) 3D and b) 2D view.

Difference between the two points in heights was measured with use of different depth of field DFD function mentioned in part 2. The contact height may vary depending on the accuracy of the contact application method which is in this case screen printing. The height of these contacts reaches an average of 21 µm, which is the typical height for cells of this type [3]. This was experimentally determined by measuring several points on the cell. As can be seen from Figure 4a, the heights of these contacts are not identical at all locations.

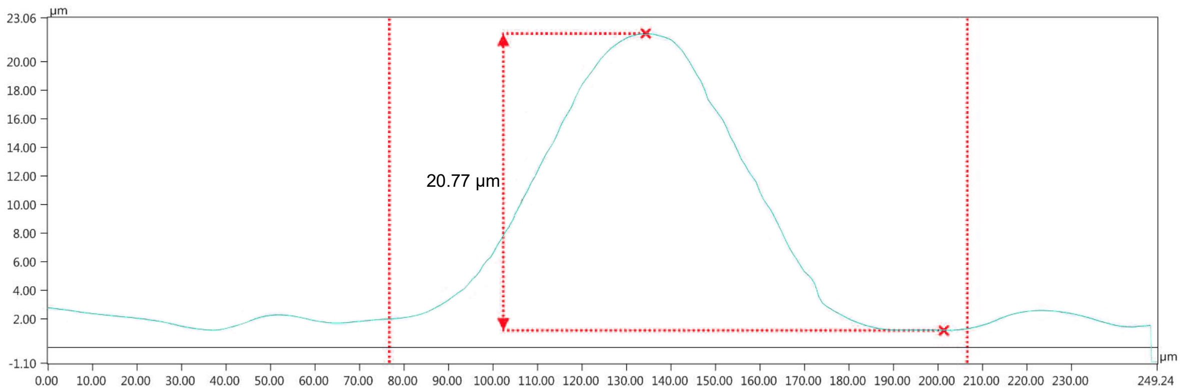


Figure 5: Height profile of the solar cell contact measured by an optical microscope.

4 CONCLUSION

From EBIC measurements and 3D digital optical microscope observations, polycrystalline Si solar cell was properly characterized and its surface and subsurface defects and impurities were found. With use of EBIC, the interface between contact and solar cell was successfully imaged. Here image contrast shows a different concentration of carriers in silver contact and Si semiconductor. The subsurface defects manifested themselves in the form of cracks, which as also shown, may lead to failure of the entire cell region. Contact was ohmic and there was no visible delamination. By optical microscope it was also measured that the application of the contact was not uniform. Besides such irregularities may lead to different current densities on the contact. Thus, described methods above have localized with great precision and certainty defects in the solar cell. That defects may have occurred during fabrication, manipulation or as a result of other types of degradation.

ACKNOWLEDGEMENT

Research described in the paper was financially supported by the Internal Grant Agency of Brno University of Technology, grant No. FEKT-S-17-4626. Part of the work was carried out with the support of CEITEC Nano Research Infrastructure (MEYS CR, 2016–2019). For the research, infrastructure of the SIX Center was used.

REFERENCES

[1] GAJDOŠ, A.; ŠKARVADA, P.; MACKŮ, R.; PAPEŽ, N.; ŠKVARENINA, Ľ.; SOBOLA, D. Isolation and optoelectronic characterization of Si solar cells microstructure defects. *Journal of Physics: Conference Series*, 2018, 1124, issue 4, p. 1-6. ISSN: 1742-6596.

[2] GAJDOŠ, A.; ŠKVARENINA, Ľ.; PAPEŽ, N.; ŠKARVADA, P.; MACKŮ, R. *Advanced methods for localization and isolation of surface defects in monocrystalline silicon solar cells*. Progress in Applied Surface, Interface and Thin Film Science - Solar Renewable Energy News 2017. Bratislava: Comenius University, 2017. s. 42-42. ISBN: 978-80-223-4411-1.

[3] PAPEŽ, N. Morphological structure of solar cells based on silicon and gallium arsenide after ion etching. *In Proceedings of the 24th Conference STUDENT EEICT 2018*. Brno: 2018. p. 513-517. ISBN: 978-80-214-5614-3.

[4] PAPEŽ, N.; SOBOLA, D.; ŠKVARENINA, Ľ.; ŠKARVADA, P.; HEMZAL, D.; TOFEL, P.; GRMELA, L. Degradation analysis of GaAs solar cells at thermal stress. *Applied Surface Science*, 2018, issue 461, p. 212-220. ISSN: 0169-4332.

[5] PARISH, Ch. M.. *Electron and Ion-beam Characterization of Nitride Semiconductor Devices*. North Carolina, 2006. Doctoral thesis. North Carolina State University. Supervised by Phillip Russell.

[6] PARISH, Ch. M.; BACHTELOR D.; CURT P. and RUSSELL P. Tutorial: Electron Beam-Induced Current in the Scanning Electron Microscope. *Microscopy and Analysis*. 2007, pp. 11–13.

[7] SOBOLA, D.; PAPEŽ, N.; ŠKARVADA, P.; TOMÁNEK, P.: Srovnání metod SEM a SPM pro charakterizaci solárních článků. *Jemná mechanika a optika*, 2017, č. 62, p. 81-83. ISSN: 0447-6441.

[8] ŢĂLU, Ş.; PAPEŽ, N.; SOBOLA, D.; ACHOUR, A.; SOLAYMANI, S. Micromorphology investigation of GaAs solar cells: case study on statistical surface roughness parameters. *JOURNAL OF MATERIALS SCIENCE MATERIALS IN ELECTRONICS*, 2017, 28, issue 15, p. 1-12. ISSN: 0957-4522.